Numerical Weather Prediction

Report on development of low-probability alternative precipitation diagnoses for the UK post-processing system

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Report on development of low-probability alternative precipitation diagnoses for the UK post-processing system

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1. Abstract

A poor diagnosis of widespread freezing rain by the experimental Met Office UK post-processing system on 14th March 2006 has been investigated. A coding error has been discovered in the routine that diagnoses precipitation type. Correcting the error gave much improved results. However, some of the forecasting problems also arose from the fact that the model vertical profiles lacked a substantial warm layer aloft. Given this, a simple method for adjusting these based on expected errors in wet-bulb temperature from the operational verification system was coded up and tested on three cases. The results demonstrated that the revised procedure can now credibly produce alternative diagnoses of precipitation type, one for slightly warmer conditions and one for slightly colder conditions. The probability of either of the alternative scenarios occurring is 32%. The new procedure is cheap and efficient and should give an improved diagnosis of possible precipitation phase in marginal winter situations.

2. Background

The motivation for this work came from an internal report by Davies (2006) (Met Office Operations Centre (OPS) Chief forecaster). The report noted and discussed the poor performance of the Met Office UK Post-Processing system (UKPP) in diagnosing widespread freezing rain on the 14th March 2006. Freezing rain is potentially very dangerous for all highway users, either on foot, as a cyclist, or in a vehicle. On this day treacherous conditions on roads across northern England led to a number of serious accidents due to black ice. Kirklees Highways was urging people not to go out where possible as freezing rain had left "road gritters unable to cope". The A1 was severely affected, and the A66 was closed with three people taken to hospital following a severe road accident due to ice at East Layton. The main conclusion from Davies' report was that the Global, Mesoscale (MES) and North Atlantic and Europe (NAE) models did not properly capture a warm layer of air between 850 and 925 hPa as evidenced by the Albemarle upper air sounding made at 2300 UTC on 13th March. This aspect has been looked at from a data assimilation point of view by Semple (2006). However, some NAE model runs did resolve a layer of air above freezing and it was disturbing that the UKPP could still not diagnose freezing rain in contrast to the operational Nimrod system (working from the MES) which had some. It was decided to investigate the reason for the lack of freezing rain in UKPP outputs and to develop a way of improving the present method for the diagnosis of precipitation type. The present diagnostic scheme for precipitation phase is outlined in Appendix 1.

3. Case study 14/3/06 (freezing rain)

3.1 Synoptic situation

Developments largely hinged on the evolving upper air. An upper vortex north-west of the UK migrated south-eastwards in concert with a sharpening upper trough moving east on its southern flank. Dynamical forcing ahead of this trough caused relatively moist mid-tropospheric air to rise, resulting in fall out as snow, due to a continuing cold dry undercut from the south-east across eastern England. This is reflected in the surface pressure maps shown in Figure 1.

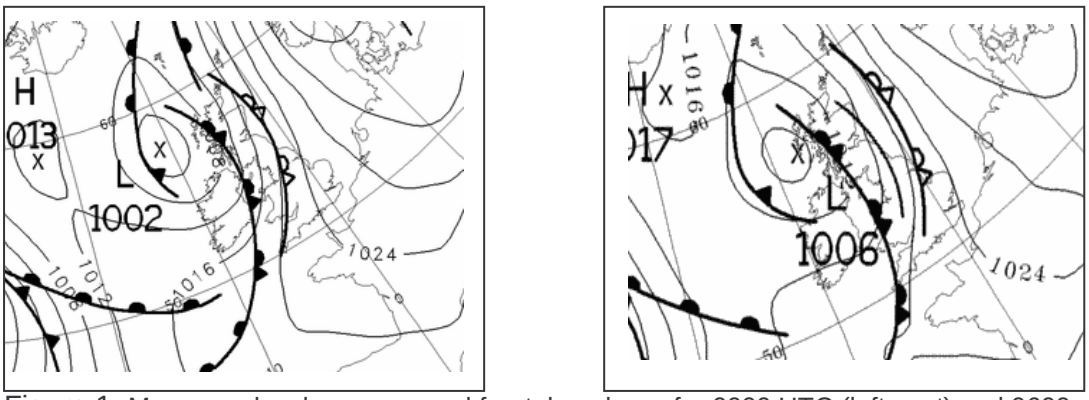


Figure 1. Mean sea-level pressure and frontal analyses for 0000 UTC (leftmost) and 0600 UTC 14th March 2006 (from Davies 2006).

The sharpening upper trough overran the surface occlusion in the west to produce the upper front and trough drawn to the east of the main occlusion. The wintry mix of precipitation occurred in association with these features and the surface occlusion marked the transition to much milder air. Plotted charts showing a mix of freezing rain, sleet and snow are shown below in Figure 2.

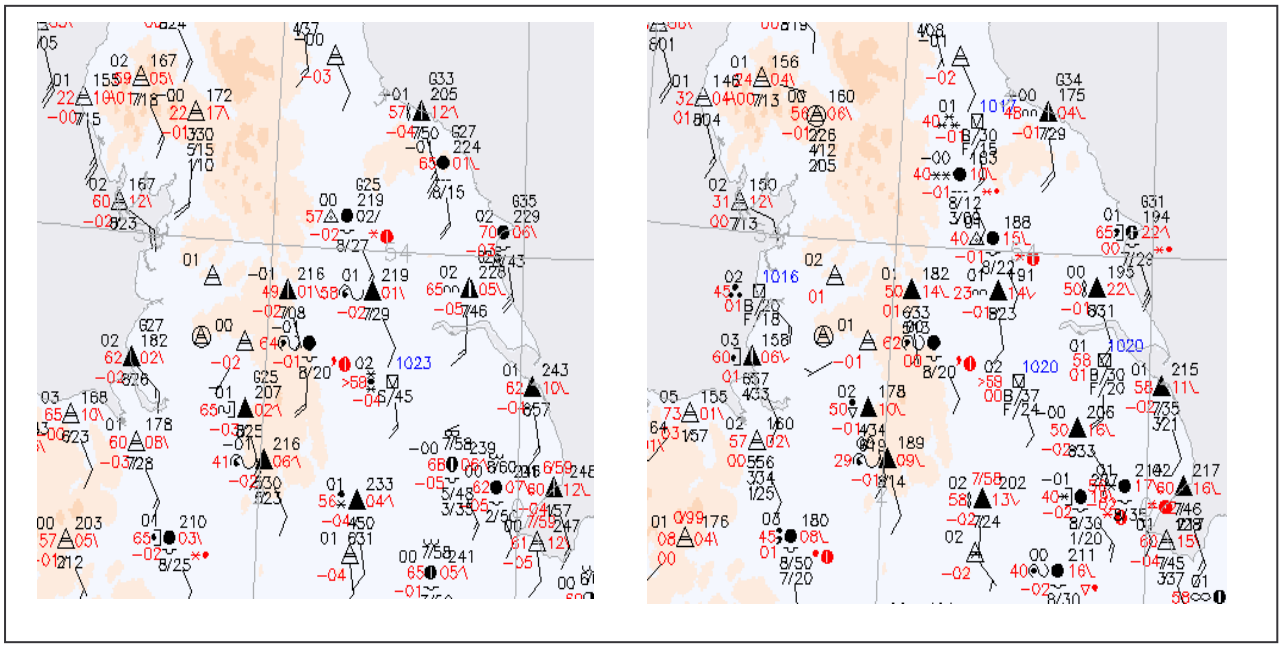


Figure 2. Plotted surface charts for 0000 UTC 14th March (leftmost) and 0600 UTC 14th March showing widespread freezing rain over northern England accompanied by sleet and snow in the east turning to rain and drizzle later in the west (from Davies 2006).

The cold dry undercut from the south-east meant that the lowest part of the boundary layer remained very cold as far west as the surface occlusion. However, milder air did leak eastwards ahead of the surface occlusion in a layer around 900 hPa and it was this warmer air that produced ideal conditions for freezing rain. The warm layer was sampled by the Albemarle upper air sounding for 2300 UTC 13th March which is shown in Figure 3.

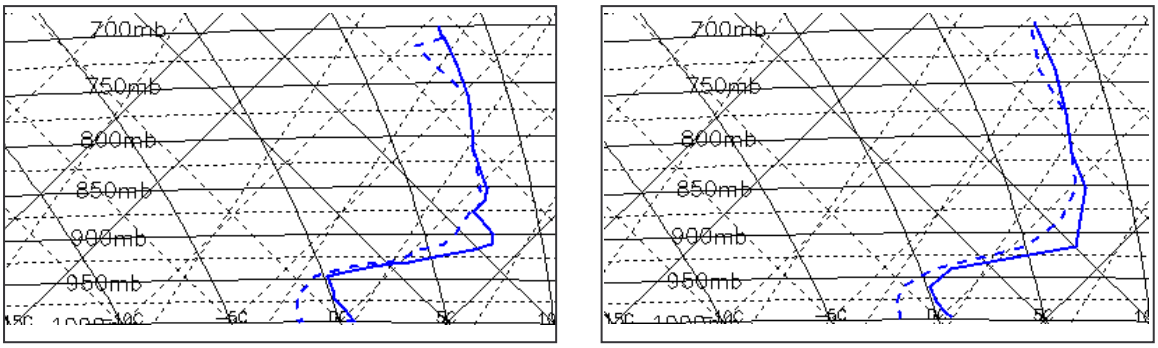


Figure 3. Upper air sounding for Albemarle (Latitude 55.01ºN, Longitude 1.52ºW) for 2300 UTC 13th March 2006. The leftmost diagram shows temperature and dew point variation on pressure levels directly from the sounding data. The rightmost diagram shows the same profile after the sounding data were interpolated onto the Met Office model levels.

The Albemarle raw sounding (leftmost in Figure 3) shows a classical freezing rain situation. Snow falling from the thick layered cloud above 850 hPa would fall into a warm layer with a maximum air temperature of 3.4 ºC at 911 hPa and wet-bulb temperatures above zero. This warm layer had a depth of circa 700 metres which would be sufficient to completely melt most of the snow descending at a typical rate of about 1 metre/sec. The raindrops would then encounter a sub-zero freezing layer from 933 hPa down to the ground. In this layer the raindrops would exist in a super-cooled state until they hit the ground after descending another 700 metres where they would freeze instantly on the cold surface thereby creating ice which would then accumulate quickly. At places where the warm layer was shallower, the snow would not melt completely and in those regions either ice pellets or sleet would reach the ground. In areas with no warm layer (wet-bulbs remaining below freezing), precipitation would reach the ground as snowflakes, for example, over parts of NE England at 0600 UTC.

3.2 Diagnosing precipitation type at Albemarle in the UKPP

As a first step in trying to understand the reasons for the poor diagnosis of freezing rain in the UKPP it was decided to see what the UKPP would produce if it was given the Albemarle profile as data. The first stage of that process was to interpolate the original sounding data onto the model levels. The result of this interpolation is shown in Figure 3 (rightmost diagram). Comparing the two diagrams in Figure 3 it is clear that the Met Office models have sufficient vertical resolution in the lower troposphere to resolve profiles like Albemarle. The interpolated profile lacks some detail, for example at 875 hPa, but the main features are still there; a cold near-saturated layer above 850 hPa, a substantially warmer layer down to 925 hPa and a very cold layer below this down to the surface. Running this profile through the parallel operational UKPP software gave a precipitation type diagnosis of ‘snow’. Clearly something was amiss. After further investigation it was discovered that a programming error introduced by the vectorisation of the original Nimrod code meant that the height integral of positive wet-bulb temperatures was not being done correctly. Correcting the programming bug gave a correct diagnosis of ‘freezing rain’. The conclusion from this was that the original Nimrod scheme as implemented in the UKPP was capable of diagnosing freezing rain provided the forecast profile was correct. The discovery of this error explained why the Nimrod diagnoses were better than those from the UKPP as noted in Davies’ report.

3.3 Precipitation type from Mesoscale model (MES) data

Met Office Mesoscale model (MES) data were readily available for this case from the operational archive and the corrected code was run with these data in order to assess the wider impact. The results are shown in Figure 4.

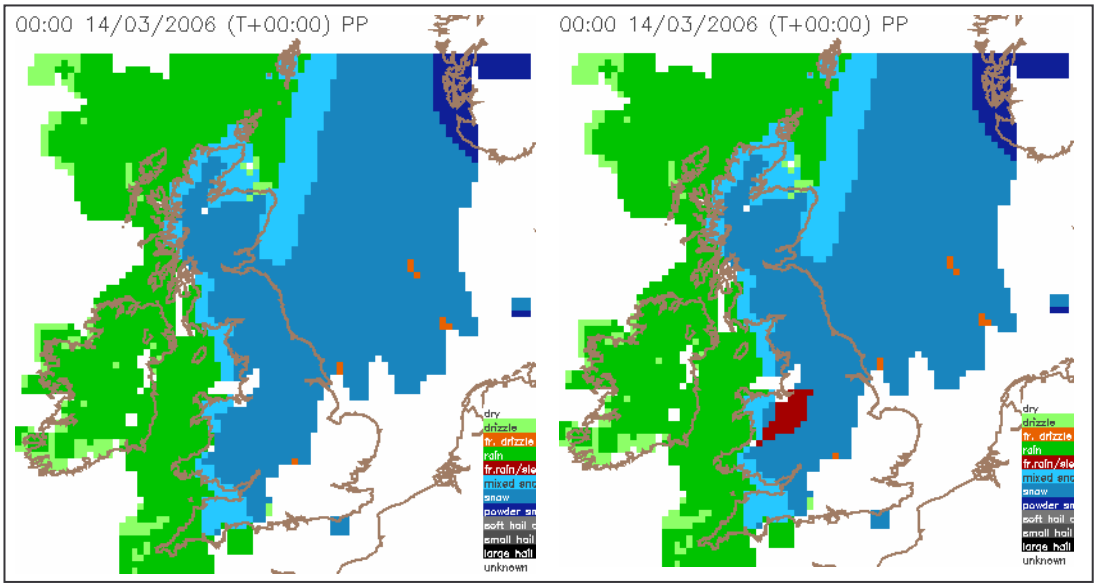
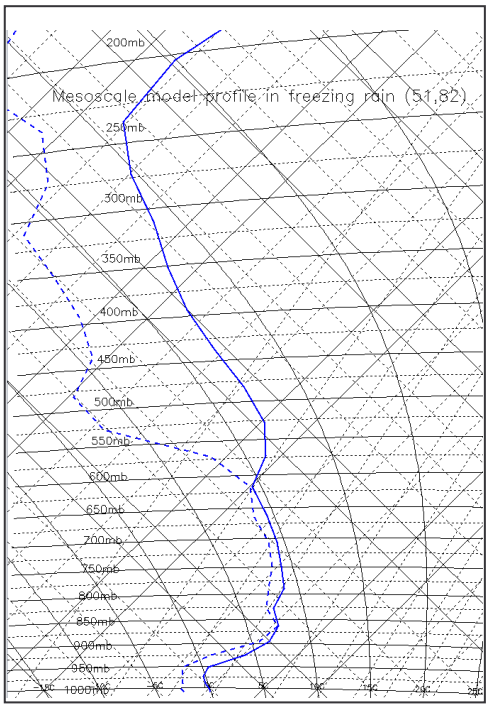


Figure 4. Precipitation type diagnoses for 0000 UTC 14th March 2006 T+0 from the MES model. The left diagram was produced using the original operational UKPP code and the right diagram from code that has been corrected (see text).

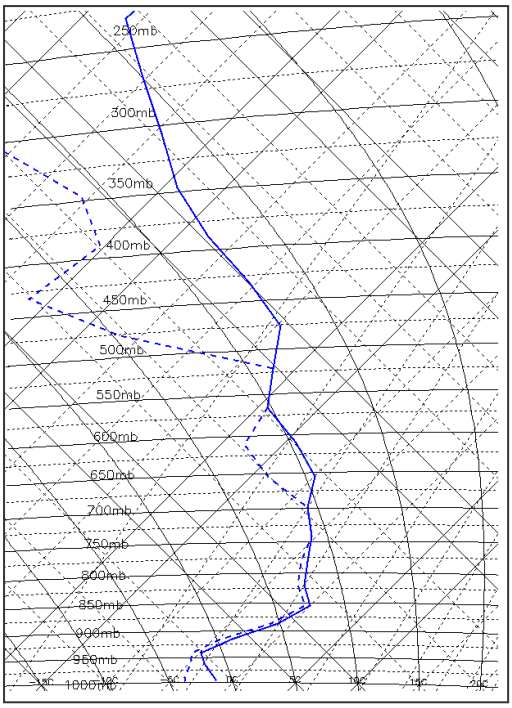
The impact of correcting the coding error is self-evident. In the operational version (left image), no freezing rain is diagnosed anywhere, just 'mixed snow and rain' (snow on high hills with rain lower down) and 'snow'. However, after correcting the error a large area of freezing rain is diagnosed over Wales into NW England. In this area the probability of snow was reduced due to the corrected code now taking into account elevated warm areas in the MES vertical profiles which the uncorrected code did not. The large freezing rain area is a much improved signal. A tephigram from a point in the middle of the freezing rain area (Figure 5) shows that the MES has captured a warm layer aloft and now the post-processing scheme correctly diagnoses freezing rain as opposed to snow.



In Figure 4 there are a few pixels showing freezing drizzle. Correcting the coding error made no difference to these since drizzle is always diagnosed if; the rainfall rate is less than 0.25 mm/h, there is no convection and the precipitating cloud top temperature is greater than -1.0°C. In that case no reference is made to the wet-bulb temperature profile. Freezing drizzle is diagnosed when the wet-bulb temperature at model level 1 (nearest surface) is below freezing.

Figure 5. Tephigram from the MES at 0000 UTC 14th March 2006 T+0 in the centre of the diagnosed freezing rain area shown in Figure 4.

4. Providing alternative diagnoses of precipitation type for slightly warmer and colder profiles



Even though the code correction gave an improved precipitation type diagnosis, there was still no freezing rain diagnosed further north over northern England. The reason for this is clear from the MES model tephigram for a point near Leeds and shown in Figure 6.

The temperature is below freezing throughout this profile with the warm air that was evident in the Albemarle sounding below 850 hPa absent. Clearly this is incorrect given that freezing rain was falling in the Leeds area. However, the model was "close" to having an "above freezing" layer just below 850 hPa. Clearly by increasing the model's temperature in the lower troposphere, the probability of snow at the ground would decrease and the final diagnosis of precipitation type would eventually change. Therefore, a way of quantifying wet-bulb temperature uncertainty based on verification data was required.

Figure 6. Tephigram from the MES at 0000 UTC 14th March 2006 T+0 near Leeds.

4.1 Quantifying wet-bulb temperature uncertainty

Use was made of the operational Area Based Verification (ABV) against radiosondes for the reduced NAE area to get an idea of the likely magnitude of model temperature errors in the vertical. The results of this data extraction are shown in the Table 1 below.

Mean	T+0	T+6	T+12	T+18	T+24	T+30	T+36	T+42	T+48
1000 hPa	0.23	0.23	0.24	0.24	0.22	0.20	0.18	0.19	0.17
850	0.07	0.06	0.12	0.10	0.14	0.13	0.15	0.20	0.15
700	-0.03	-0.05	0.05	0.08	0.04	0.16	0.18	0.25	0.23
500	-0.03	-0.05	0.05	0.19	0.13	0.22	0.23	0.31	0.30
400	-0.05	-0.08	0.00	0.04	0.06	0.12	0.11	0.20	0.20
SD	T+0	T+6	T+12	T+18	T+24	T+30	T+36	T+42	T+48
1000 hPa	0.85	0.68	1.07	1.15	1.19	1.28	1.36	1.44	1.49
850	0.84	1.02	1.07	1.17	1.26	1.34	1.43	1.54	1.59
700	0.72	0.87	0.92	1.02	1.10	1.19	1.27	1.37	1.46
500	0.63	0.77	0.82	0.95	1.02	1.02	1.18	1.39	1.54
400	0.64	0.79	0.85	1.00	1.08	1.20	1.30	1.39	1.51

Table 1. 12 month running mean errors and standard deviation (SD) of temperature for differences (NAE – sonde) up to the end of March 2006.

Using twelve-monthly running mean data meant that the results were stable and would have encompassed a variety of situations up to the end of winter 2005/6. The key slice of atmosphere for stratiform precipitation type forecasting is the layer from the ground up to 2000m (circa 800hPa). In Table 1 this is represented with results at 1000 and 850 hPa. At T+0 the average mean error and standard deviation (SD) for these two levels is +0.15 and 0.85 respectively. An estimate of likely temperature errors for the layer 0-2000m is shown in Table 2 below.

0-2000m	T+0	T+6	T+12	T+18	T+24	T+30	T+36	T+42	T+48
Mean error	0.15	0.15	0.18	0.17	0.18	0.17	0.17	0.19	0.16
SD of error	0.85	0.85	1.07	1.16	1.23	1.31	1.39	1.49	1.54

Table 2. Estimate of 12 month running mean errors and standard deviation of temperature for (NAE – sonde) in the layer 0-2000m up to end of March 2006

The statistics in Table 2 can be converted to give the expected difference of real temperature from model temperature corresponding to plus or minus one standard deviation of error after removing the bias. Assuming that temperature errors are normally distributed, the positive and negative increments from model profiles will then each have probabilities of occurrence of 16% giving a combined probability of 32% for an alternative precipitation diagnosis. The expected temperature increments are shown in Table 3.

0-2000m	T+0	T+6	T+12	T+18	T+24	T+30	T+36	T+42	T+48
Positive increment	0.70	0.70	0.89	0.99	1.05	1.14	1.22	1.30	1.38
Negative increment	-1.00	-1.00	-1.25	-1.33	-1.41	-1.48	-1.56	-1.68	-1.70

Table 3. Estimate of positive and negative increments of temperature corresponding to one standard deviation for (NAE – sonde) with bias removed in the layer 0-2000m using 12 month running statistics up to end of March 2006.

The positive and negative increments for T+0 were applied to the MES model profiles obtained for the 14/3/06 case. (At T+0 there were only small differences between the verification results for NAE and MES, so it was a fair test to apply NAE statistics to the MES). These then produced two alternative precipitation type outputs. One corresponded to a warming of the 0-2000m layer (excluding level 1), and the other a cooling (excluding level 1). Level 1 was excluded as the object of the exercise is to assess the likely impact of model errors aloft on the diagnosis of precipitation type. Results are discussed later.

4.1.2. Discussion

The statistics presented in Tables 1 to 3 are all concerned with temperature. However, in the current precipitation type diagnosis scheme it is wet-bulb temperature that is used. Wet-bulb temperature depends both on temperature and humidity. If both temperature and humidity errors are considered then sorting out possible combinations gets rather complicated and was beyond the scope of the resources allocated to this work. However, in stratiform precipitation, the relative humidity is likely to be high anyway (>80%) and model vertical error distributions in relative humidity are likely to be highly influenced by incorrect forecasting of inversions and dry zones aloft. These are not relevant for stratiform precipitation diagnosis. Therefore, relative humidity errors have been ignored in this paper.

In the precipitation type code, wet-bulb temperature is calculated from model vertical profiles of temperature and relative humidity. This is a relatively expensive operation and it was desirable to avoid re-calculating the wet-bulb temperatures for each of the warmer and colder temperature increments. Therefore, investigations were conducted to determine whether it would be feasible to add on the increments directly to the derived central wet-bulb temperatures. To do this the wet-bulb changes according to a range of temperature and relative humidity were examined. The results of this analysis are shown in Table 4.

Change in wet-bulb per degree change in temperature					
	Relative humidity				
Temp ºC	10%	30%	50%	70%	100%
20	0.49	0.65	0.80	0.94	1.00
15	0.54	0.68	0.81	0.94	1.00
10	0.59	0.71	0.83	0.94	1.00
5	0.64	0.74	0.84	0.93	1.00
0	0.69	0.77	0.85	0.93	1.00
-5	0.74	0.80	0.87	0.93	1.00
-10	0.79	0.83	0.88	0.92	1.00
-15	0.84	0.87	0.89	0.92	1.00
-20	0.89	0.90	0.91	0.92	1.00

Table 4. Change in wet-bulb temperature per degree change in temperature for a range of temperature and relative humidity values. Shading indicates a critical set of temperature and relative humidity ranges referred to in the text.

The important range of temperatures for precipitation type variation is +5 ºC to -5 ºC and these will normally occur with relative humidity above 70% where precipitation is falling. This critical temperature and humidity set has been shaded in Table 4. It can be seen that increasing or decreasing the temperature by one degree in this set will produce about a one degree change in wet-bulb temperature. It is therefore possible to add the warm and cold temperature increments directly to the central wet-bulb temperatures with only a small loss of accuracy. The warmer and colder increments for T+0 were then added to the central (raw) model values in the 14/3/06 case resulting in three outputs of precipitation type and other diagnostics.

4.2. Results

4.2.1 Precipitation type

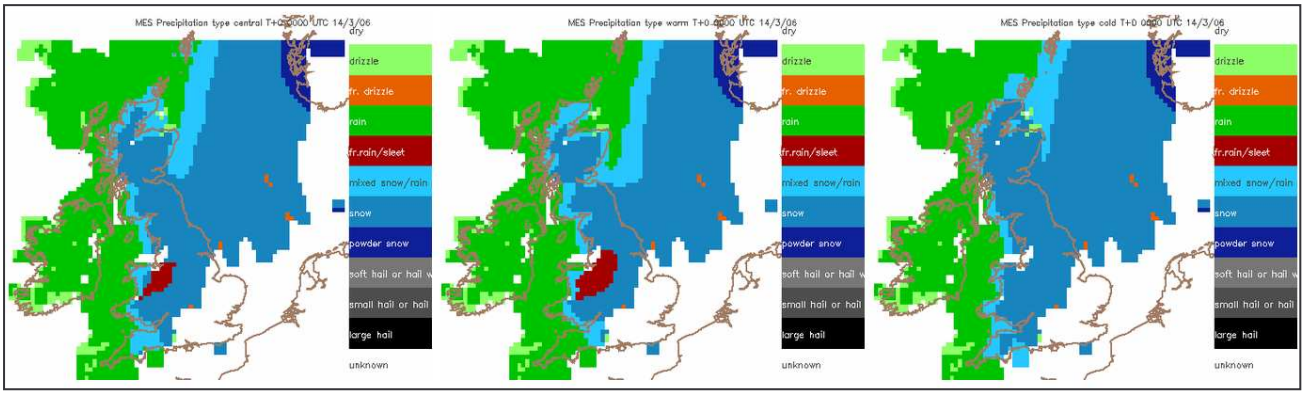
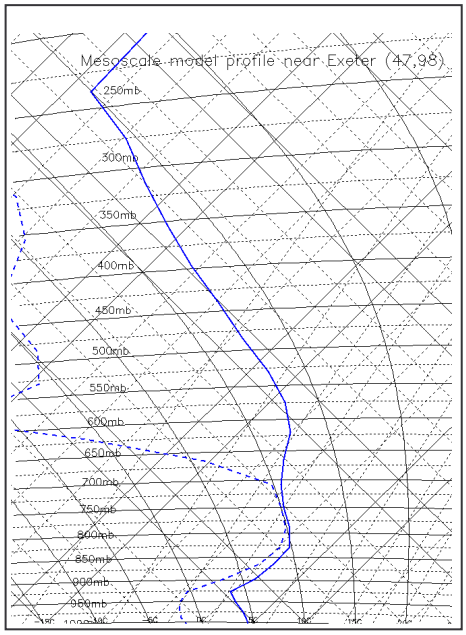


Figure 7. Output diagnoses of precipitation type for T+0 0000 UTC 14/3/06. Leftmost picture is from the control "central" run, middle picture is from the "warmer" scenario and the rightmost picture is from the "colder" scenario. Each of the "warmer" and "colder" scenarios has a 16% probability of occurrence.

In Figure 7 it is clear that increasing temperatures in the lowest 2000m by 1 SD enlarges the area of freezing rain over northern England beneficially (although still not far enough). In the same diagram, the area of snow is reduced (again correctly) and it is now raining over Devon as opposed to - "mixed" with snow on Dartmoor. At Haytor on Dartmoor (310m asl) there was some snow on the 13th but by midnight the temperature had risen to +2.8 ºC and on the 14th there was rain and drizzle. Davies (2006) demonstrated that the model was too cold in the

critical layers and the better results for the “warmer” chart shows that with improved profiles, a superior diagnosis can be made (albeit as a low probability alternative). The “colder” run, as expected, diagnoses more snow, which on this occasion was incorrect. The point is though, that if the OPS Centre forecasters were given alternative forecast charts then they could decide (by looking at whether the model is too warm or cold, or has missed an inversion) which one to go with. The charts also highlight areas that are sensitive to small changes in temperature, which would be another useful piece of information, for example, over SW England where either ‘rain’, ‘mixed’, or ‘snow’ types are possible. This uncertainty is illustrated by the MES model tephigram for Exeter shown in Figure 8.



In this tephigram the model’s wet-bulb temperature is close to freezing in the layer from 800 hPa down to 950 hPa meaning that the form of precipitation will be sensitive to small changes in wet-bulb temperature.

Figure 8. MES model profile from a point near Exeter at 0000 UTC 14/3/06.

4.2.2 Wet-bulb freezing level

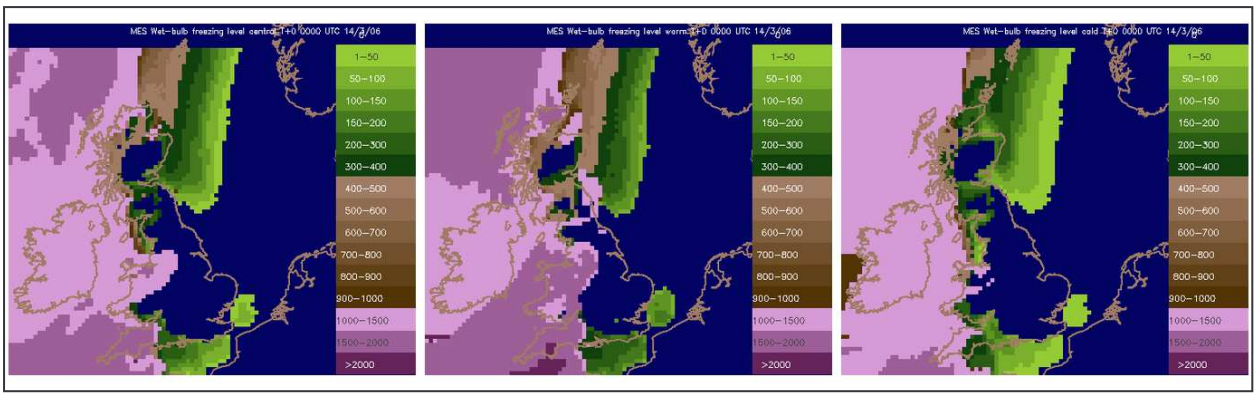


Figure 9. Outputs of wet-bulb freezing level. Leftmost picture is from the control “central” run, middle picture is from the “warmer” scenario and the rightmost picture is from the “colder” scenario.

Over the Exeter area the wet-bulb freezing level falls from 2023m in the “warmer” run down to circa 1700m in the “central” run and 317m in the “colder” run. Thus, the level changes by 1706 metres if the wet-bulb temperature is decreased by 1.7 ºC in the critical layers between 820 and 870 hPa. This result demonstrates that small changes in temperature can raise or lower the wet-bulb freezing level appreciably in marginal snow situations when the wet-bulb is close to freezing over a substantial layer.

4.2.3 Height integral of positive wet-bulb temperature

This is shown in Figure 10. This parameter is used in the UKPP procedure for determining snow probability.

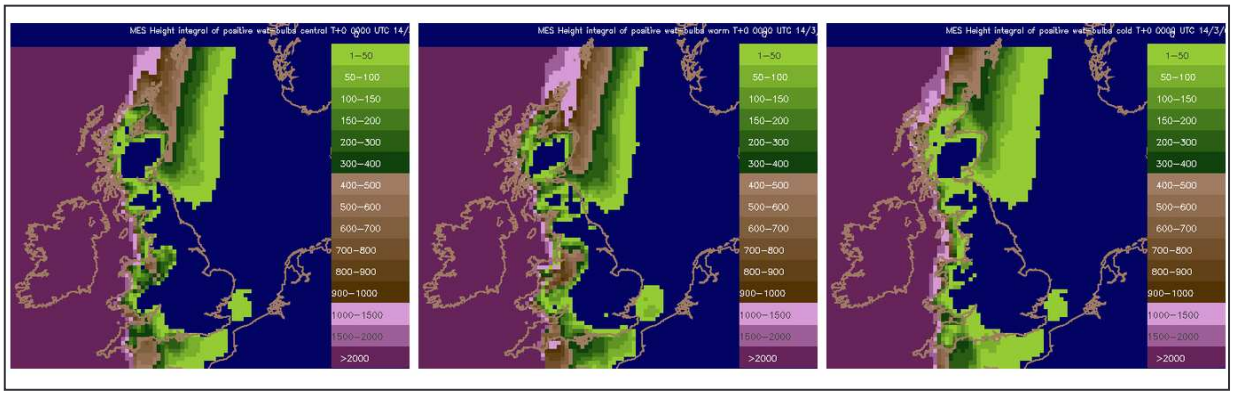


Figure 10. Outputs of height integral of positive wet-bulb temperatures. Leftmost picture is from the control “central” run, middle picture is from the “warmer” scenario and the rightmost picture is from the “colder” scenario.

Near Exeter the height integral varies from 715 Kelvin metres in the “warm” run down to 196 Kelvin metres in the “cold” run. This would equate to a probability of snow in the operational algorithm of 0% in the “warm” run and 60% in the “cold” run. So once again, like the wet-bulb freezing level, we have some sensitivity to small changes in wet-bulb temperature values; however, this diagnostic does take into account changes throughout the 0-2000m layer unlike the wet-bulb freezing level diagnostic which is only looking at one level.

4.2.4 Snow probability

The snow probability outputs for this case are shown in Figure 11.

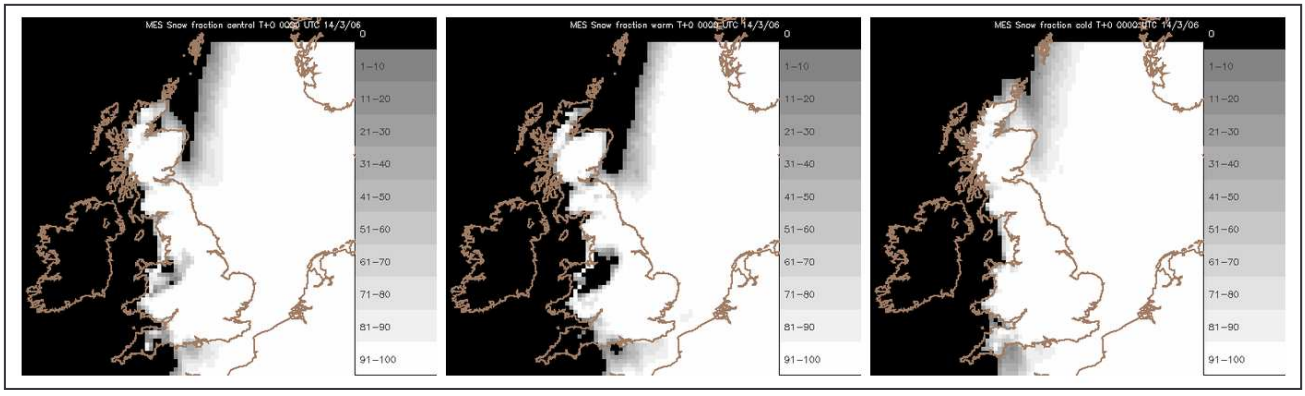


Figure 11. Outputs of snow probability (%), black is 0% and white is >80%. Leftmost picture is from the control “central” run, middle picture is from the “warmer” scenario and the rightmost picture is from the “colder” scenario.

These outputs clearly show the sensitivity of some areas of the UK to small changes in temperature resulting in large changes in snow probability. For example, the central lowlands of Scotland, the northwest Highlands, NW England, the northern half of Wales and SW England.

5. Case study 23/2/06 (rain, sleet and snow)

This case was another marginal event with a warm front moving westwards bringing snow to western areas turning to rain in the east as milder air off the North Sea was advected southwards. The synoptic situation at 1200 UTC is shown in Figure 12.

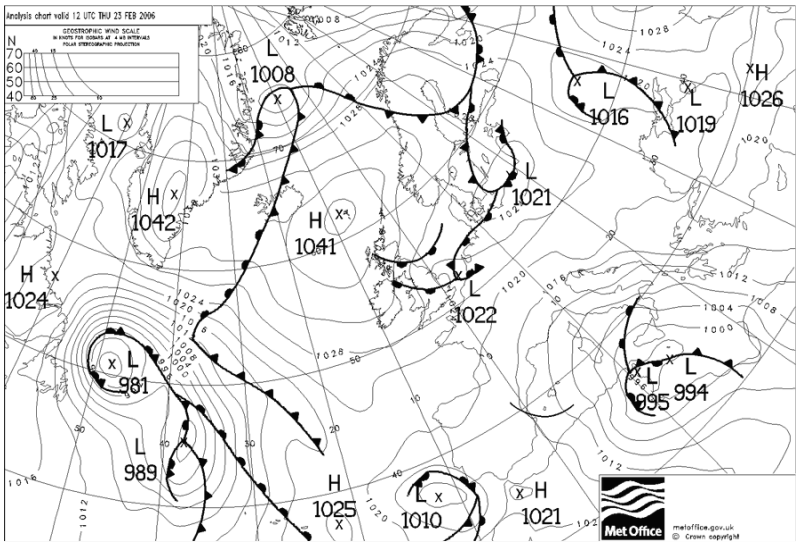


Figure 12. Surface synoptic analysis for 1200 UTC 23/2/06.

The anticyclone near the Faeroes had been responsible for introducing very cold continental air from the east into the UK during the preceding days. However, the warm front associated with the developing low in sea area Thames was causing precipitation and a flow of milder air off the North Sea. Precipitation initially fell mostly as snow to the south and west of the warm front but then turned to sleet and rain as the front passed through. This can be clearly seen in the plotted observations for parts of England shown in Figure 13 overleaf.

South and west of the warm front wet-bulb temperatures are close to freezing with widespread sleet and snow (heavy in places). To the north of the front wet-bulbs rise quickly to 2-3 ºC and over 5 ºC on the Yorkshire coast. The cold airmass west of the front is evident in the MES analysis tephigram for Exeter at 1200 UTC shown in Figure 14. Here, wet bulb temperatures are well below freezing in the boundary layer. However, in contrast, the tephigram for an area west of the Wash near Grantham shows an isothermal layer up to 930 hPa with wet-bulb temperatures just close to freezing. Judging by the surface weather reports this was a little too cold.

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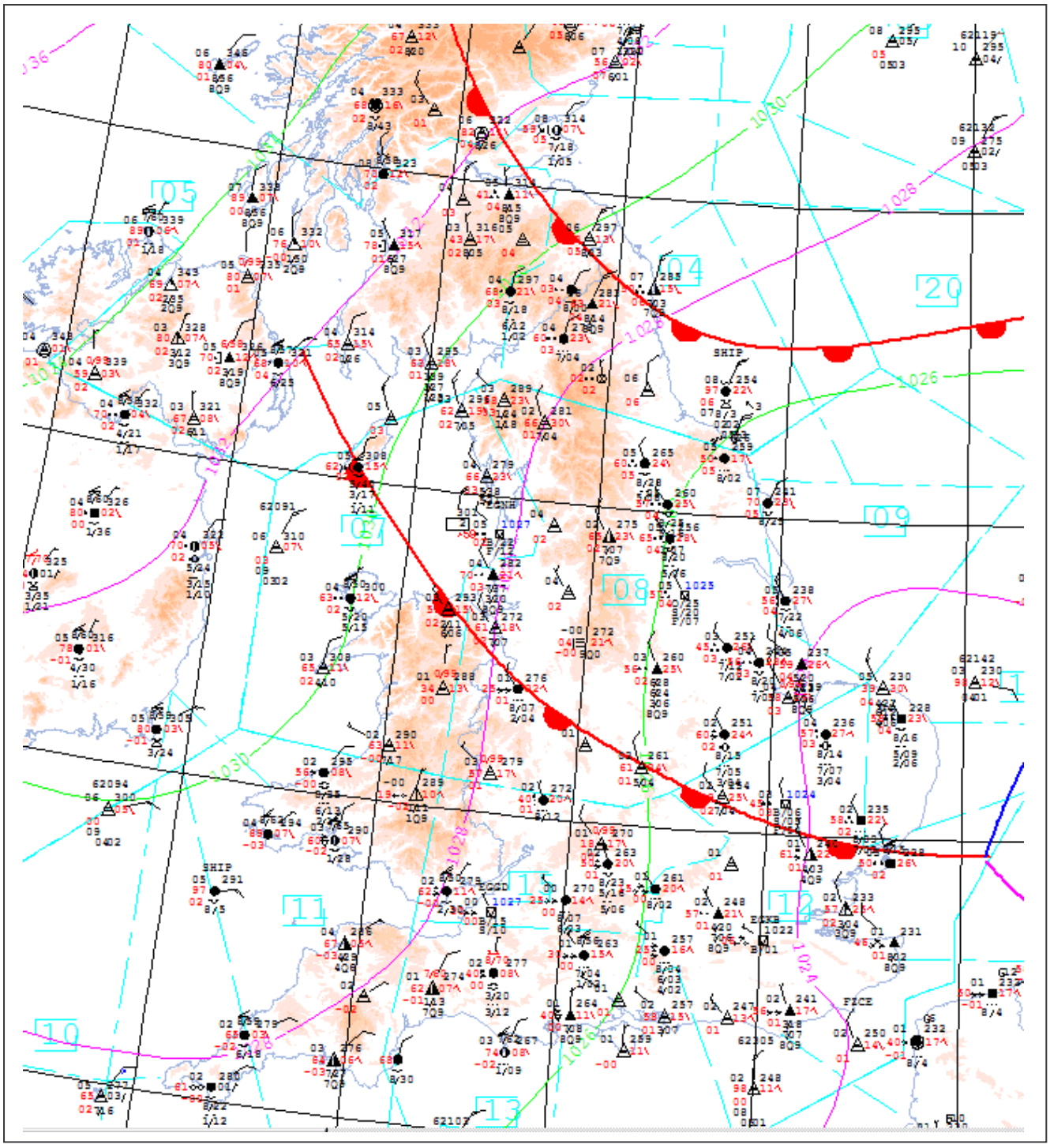

Figure 13. Plotted surface observations for 1200 UTC 23/2/06.

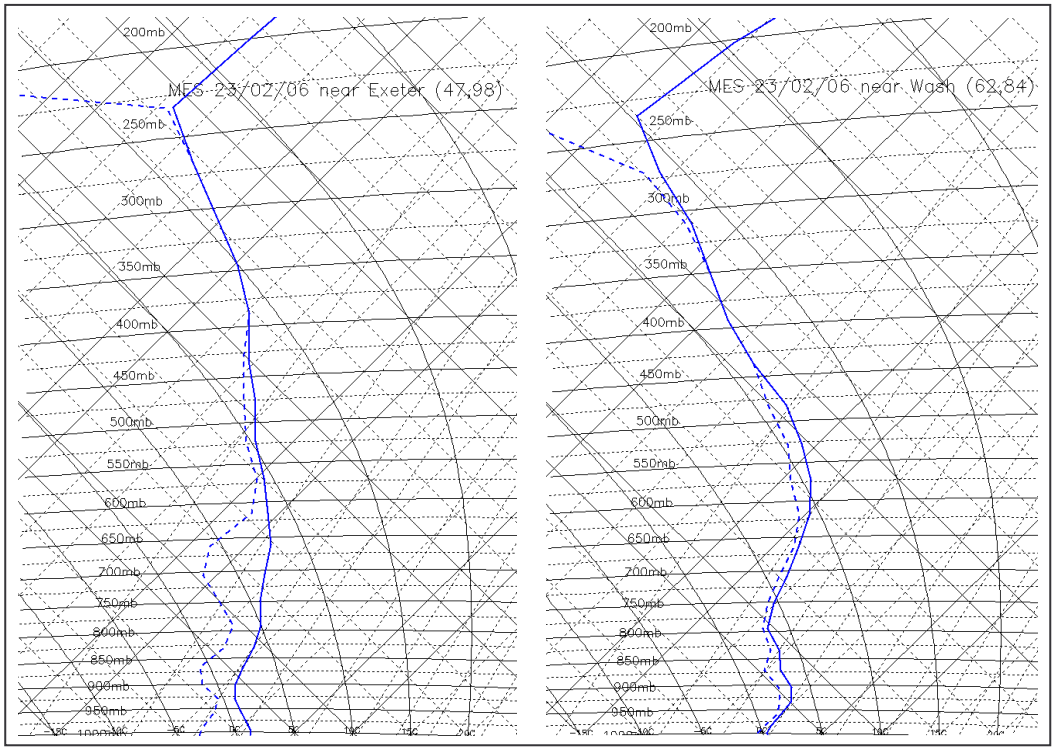

Figure 14. MES tephigrams for 1200 UTC 23/2/06. Leftmost plot is for a point near Exeter and the rightmost plot is for a point west of the Wash (near Grantham).

The T+0 diagnoses of precipitation type are shown in Figure 15.

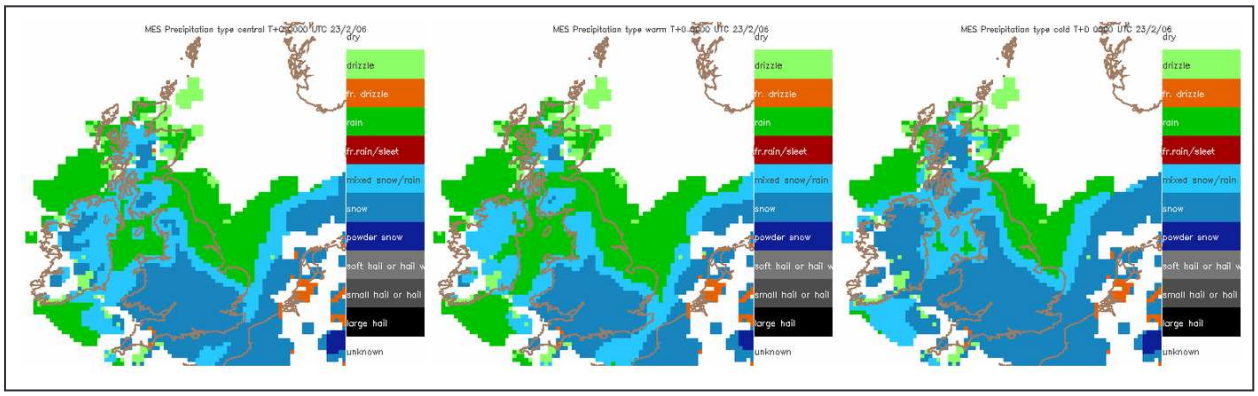

Figure 15. Output diagnoses of precipitation type for VT T+0 1200 UTC 23/2/06. Leftmost picture is from the control "central" run, middle picture is from the "warmer" scenario and the rightmost picture is from the "colder" scenario.

The area of diagnosed snow is less in the warmer scenario than in the operation central run. The reduction has occurred north of the warm front over the hills of northern England and over eastern England. The rain/sleet and sleet/snow boundaries have moved 2 or 3 pixels to the southwest in the sensitive area around the warm frontal zone. The impact of raising boundary layer temperatures is more pronounced in Figure 16 which shows a 24 hour forecast from the MES with a precipitation type diagnosis. In this diagram T+0 precipitation has been used in order to easily compare changes in the upper air and wet-bulb increments at T+24 with those at T+0. Strictly, one should not be using error statistics at T+24 for the NAE with data from the MES; however, it does serve to illustrate the potential value of providing warmer and colder scenario solutions.

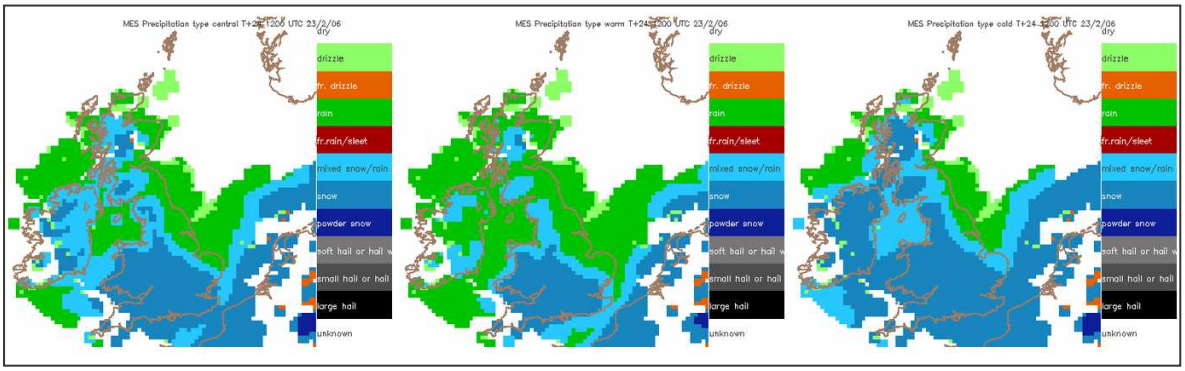

Figure 16. Output diagnoses of precipitation type for VT T+24 1200 UTC 23/2/06. Leftmost picture is from the control "central" run, middle picture is from the "warmer" scenario and the rightmost picture is from the "colder" scenario.

This forecast would have clearly alerted forecasters to the possibility that the air coming in off the North Sea only had to be slightly warmer than the raw model (central run) suggested for snow to turn more quickly to rain behind the warm front. The signal, therefore, would have been useful.

6. Case study 15/1/06 (rain and hill snow)

The previous two cases were both marginal widespread wintry precipitation events. So it was decided to examine a case which was clearly rain at low-level but with the possibility of snow on higher ground. The synoptic situation is shown in Figure 17.

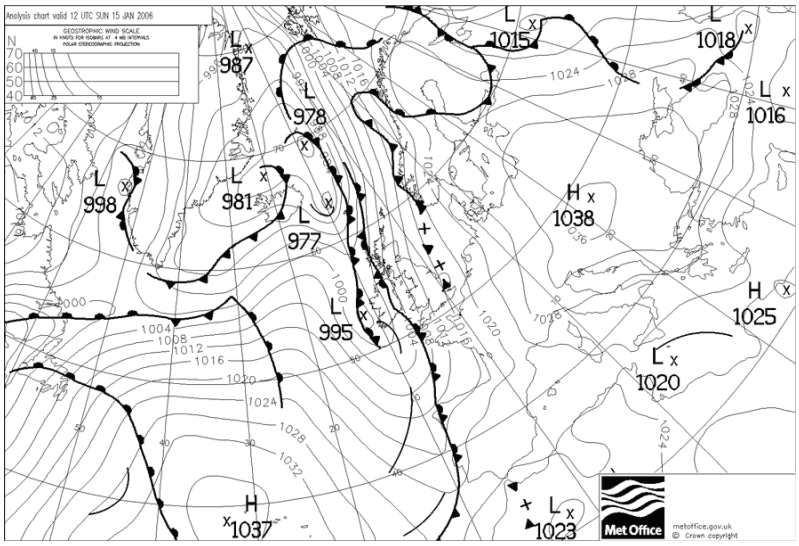

Figure 17. Surface synoptic analysis for 1200 UTC 15/1/06.

On this day a mild southerly airflow ahead of a slowly advancing occlusion from the west was evident. The only wintry precipitation observed was over high ground above 700m ASL in the north of Britain. The precipitation type diagnosis for this time is shown in Figure 18.

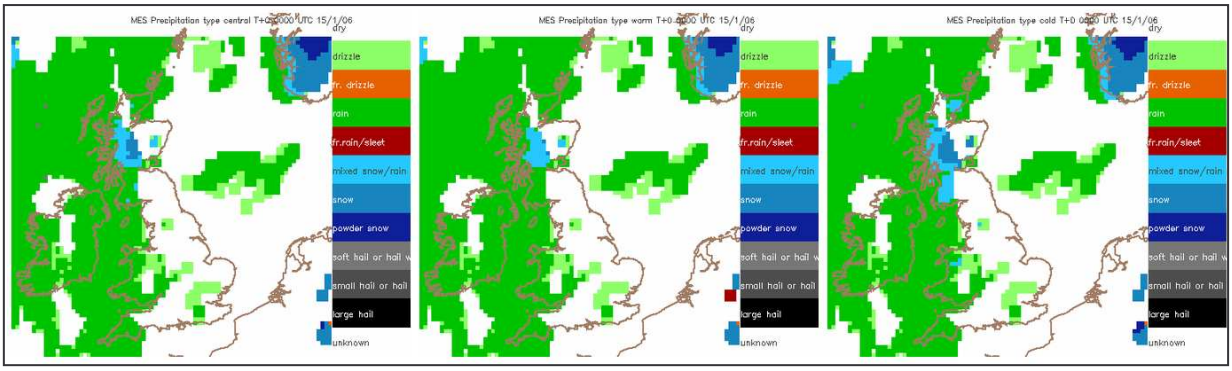

Figure 18. Output diagnoses of precipitation type for VT T+0 1200 UTC 15/1/06. Leftmost picture is from the control "central" run, middle picture is from the "warmer" scenario and the rightmost picture is from the "colder" scenario.

Apart from some snow over the Welsh mountains in the "colder" scenario, all of the wintry precipitation is confined to the high ground over Scotland. "Mixed snow/rain" means that higher peaks will have snow and lower down will see rain. The signal is that if the air is milder than the MES analysis suggests then any snow will be confined to the highest parts of Scotland, however, slightly colder conditions would imply some snow on lower hills nearer the coast and further south. Both would be useful signals for forecasters.

7. Conclusions and Recommendations

7.1 Conclusions

- A simple and efficient, scientific way of displaying low probability alternative outputs of precipitation type from the UKPP system has been coded and tested on a marginal snow and freezing rain case and a case with very little wintry precipitation.

- The results demonstrate that the procedure is capable of adding additional value to existing outputs by answering the question - what would happen if the model temperature in the lower atmosphere was a bit warmer or colder?

- Outputs of wet-bulb freezing level and height integral of positive wet-bulb temperature has demonstrated sensitivity of the present UKPP precipitation type diagnosis scheme to small temperature changes in the vertical in critical/marginal areas.

7.2 Recommendations

- It is recommended that the procedure described above for deriving alternative outputs of precipitation type based on a 32% probability of warmer or colder conditions in the atmospheric layer below 2000 metres AGL be trialled during the winter of 2006/7.

8. References

Davies (2006). "Freezing rain event Tuesday 14th March 2006". Unpublished internal Met Office document.

Semple (2006). "Investigation into the Global Model Data assimilation for the Freezing Rain Event of Tuesday 14th March 2006". Met Office Forecasting Research Technical report No. 489.

Appendix 1

Outline of operational post-processing scheme for determining precipitation type in March 2006.

The process is essentially a decision tree as follows:

1. Diagnose probability of snow.

The height integral of positive wet-bulb temperatures is calculated above the appropriate orography. If this integral is less than or equal to 25 Kelvin metres then the probability of snow is set to 1. If it is greater than 450 Kelvin metres then the probability is set to zero and is allowed to vary linearly for values in between.

2. Test for hail using model convective cloud top and base temperatures and vertical velocity (w) derived from dilute model CAPE. If vertical velocity is >5m/s and cloud top temperatures are <-15 deg C and cloud base temperatures are >-5 deg C, then hail is possible. So diagnose **hail**; large hail (w>20m/s), small hail (w>10 m/s), soft hail (w>5 m/s and height integral of positive wet-bulb temperatures <5000) or rain (melted hail) if the other conditions are not met.

Otherwise,

Test for cold cloud (cloud top temperatures <-1 deg C) or rainfall rate > 0.25 mm/h or convection. If neither of these is present then diagnose **drizzle** or **freezing drizzle** depending upon whether model level 1 wet-bulb temperature is above or below freezing.

Otherwise,

3. Diagnose **powder snow** if maximum model wet-bulb temperature in vertical profile is less than –3 deg C.

Otherwise,

4. Diagnose **snow** if probability of snow is calculated to be > 60%.

Otherwise,

5 Diagnose **freezing rain** if model wet-bulb level 1 temperature is below freezing.

Otherwise,

6. Diagnose **mixed rain and snow** (snow on high hills, rain in valleys) if probability of snow is > 1%.

Otherwise,

7. Diagnose **rain**.